The Response of Lower Atmospheric Ozone to ENSO in Aura Measurements and a Chemistry-Climate Simulation

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El Niño Southern Oscillation

• The El Niño Southern Oscillation is the dominant mode of tropical variability on interannual timescales (Philander, 1989).

• ENSO has been long known to cause significant perturbations to the coupled oceanic and atmospheric circulations (Bjerknes, 1969; Enfield, 1989).

• Changes in SST in the Pacific Ocean impact the Walker Circulation.

• ENSO is known to cause significant thermal and dynamical perturbations to the atmosphere and also influences the constituent distributions.

•To the extent that we believe climate change might impact the frequency or magnitudes of future ENSOs modeling its impact on trace gases becomes increasingly important.

Simulation Description and Measurements

Goddard Earth Observing System (GEOS) Chemistry-Climate Model (CCM)

• Using the combined GMI troposphere-stratosphere chemical mechanism

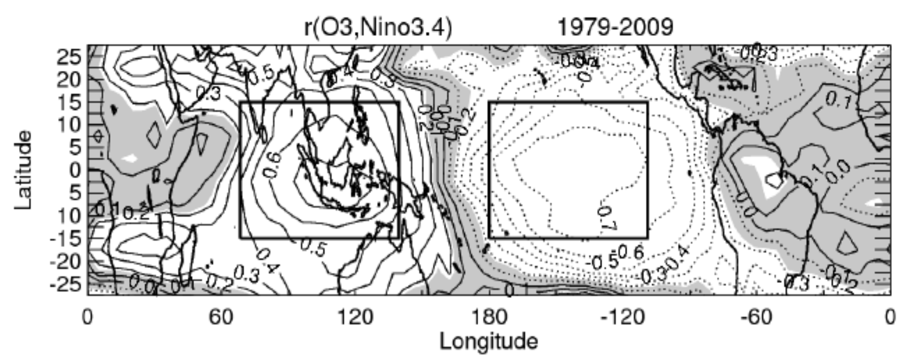
• 2 x 2.5 horizontal resolution with 72 vertical layers

• Time Slice 2005 simulation forced with observed sea surface temperatures from 1984-2009 but fixed in time natural and anthropogenic emission sources (2005)

Aura Satellite measurements:
Microwave Limb Sounder (MLS) Level 2 Version 3.3 Aug. 2004 – Jun. 2012
Tropospheric Emission Spectrometer (TES) L3 V2 Sept. 2004 – Dec. 2009

Correlation of Tropospheric Column Ozone (TCO) and Nino3.4

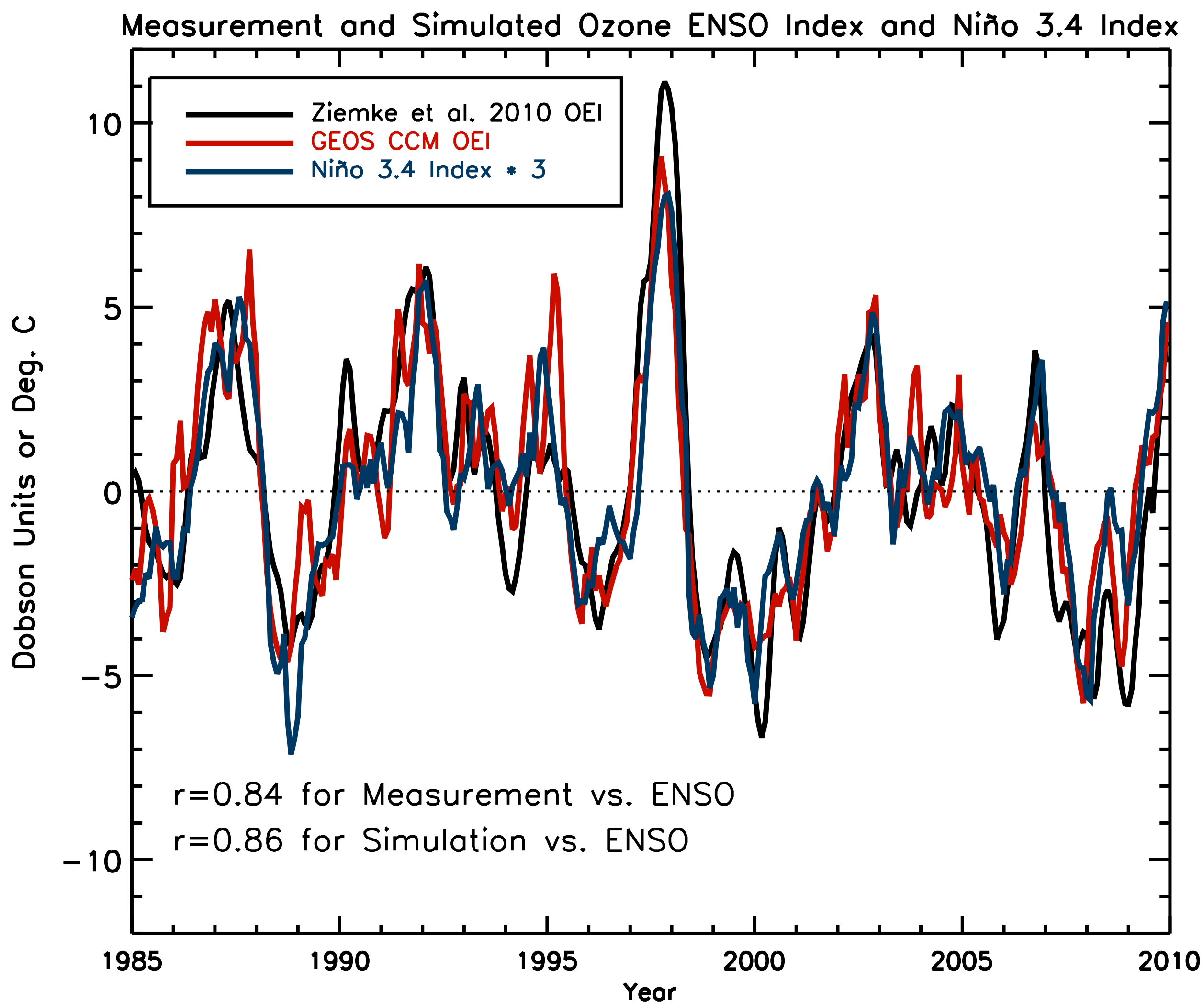
Ozone ENSO Index (OEI)
OEI = Western TCO – Eastern TCO



Ziemke et al., 2010

Comparison of the 25 year record OEI from data, model, and Niño 3.4 Index

GEOSCCM does a very good job reproducing this variability over the 1985-2009 time period.



(Multiple) Linear Regression Analysis

$$\Delta O_3(t) = \sum_j m_{X_j} \Delta X_j(t) + \varepsilon(t),$$

X_j are the different quantities that could influence ozone [e.g. for model just Niño 3.4 Index, for observations Niño 3.4 Index, QBO EOF1, and QBO EOF2]

$m_X = \partial O_3 / \partial X$ are the sensitivities of ozone to the quantity

ΔX are the changes in the different quantities

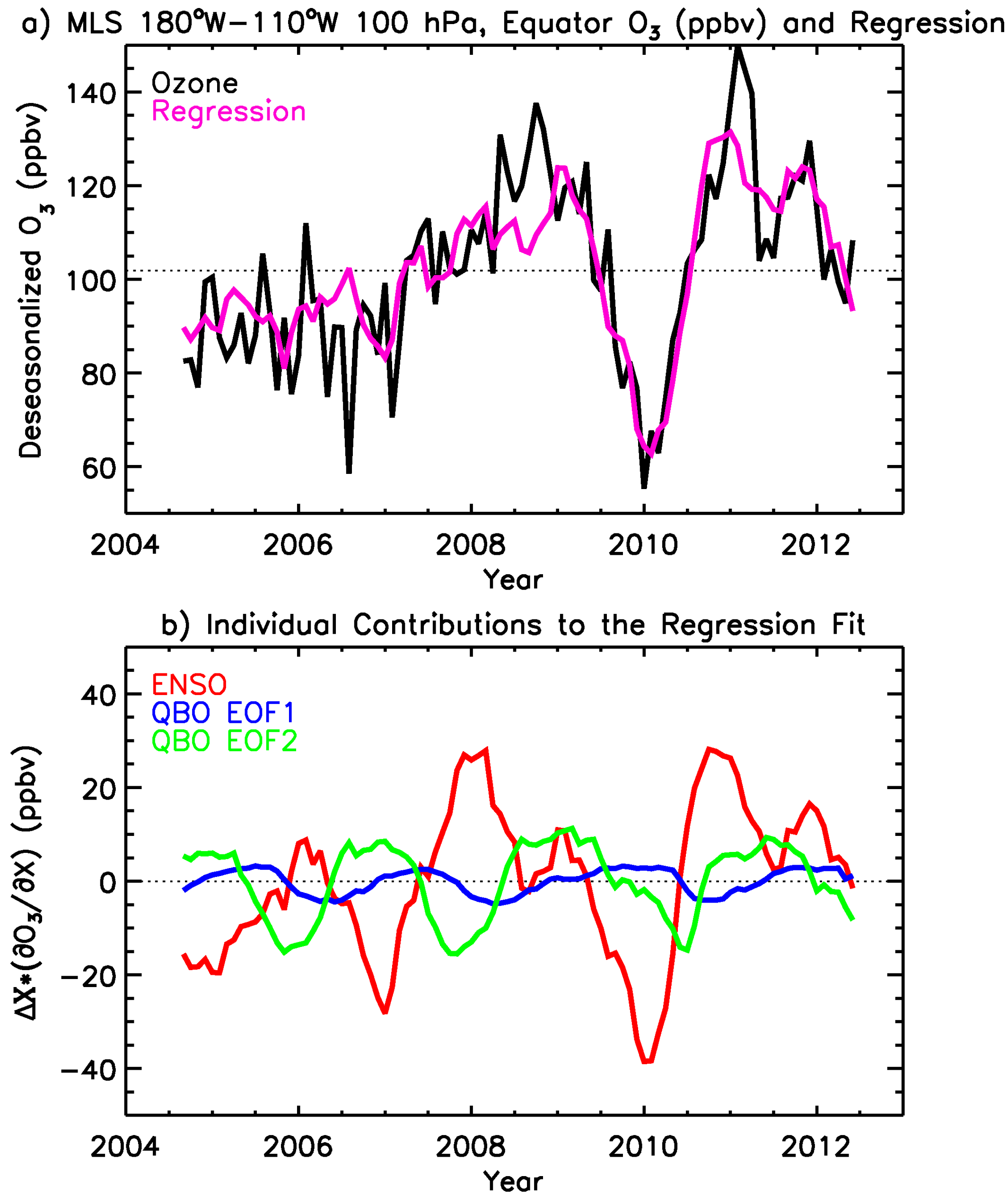
ε is the residual in the fit

Example of the Time Series and Regression Analysis

Equatorial Central and Eastern Pacific at 100 hPa for MLS deseasonalized ozone measurements

Using ENSO and the first 2 EOF of the QBO the regression analysis reproduces much of the lower frequency variability but does not reproduce the higher frequency variability.

The bottom panel shows the individual contributions (sensitivity x predictor variable).



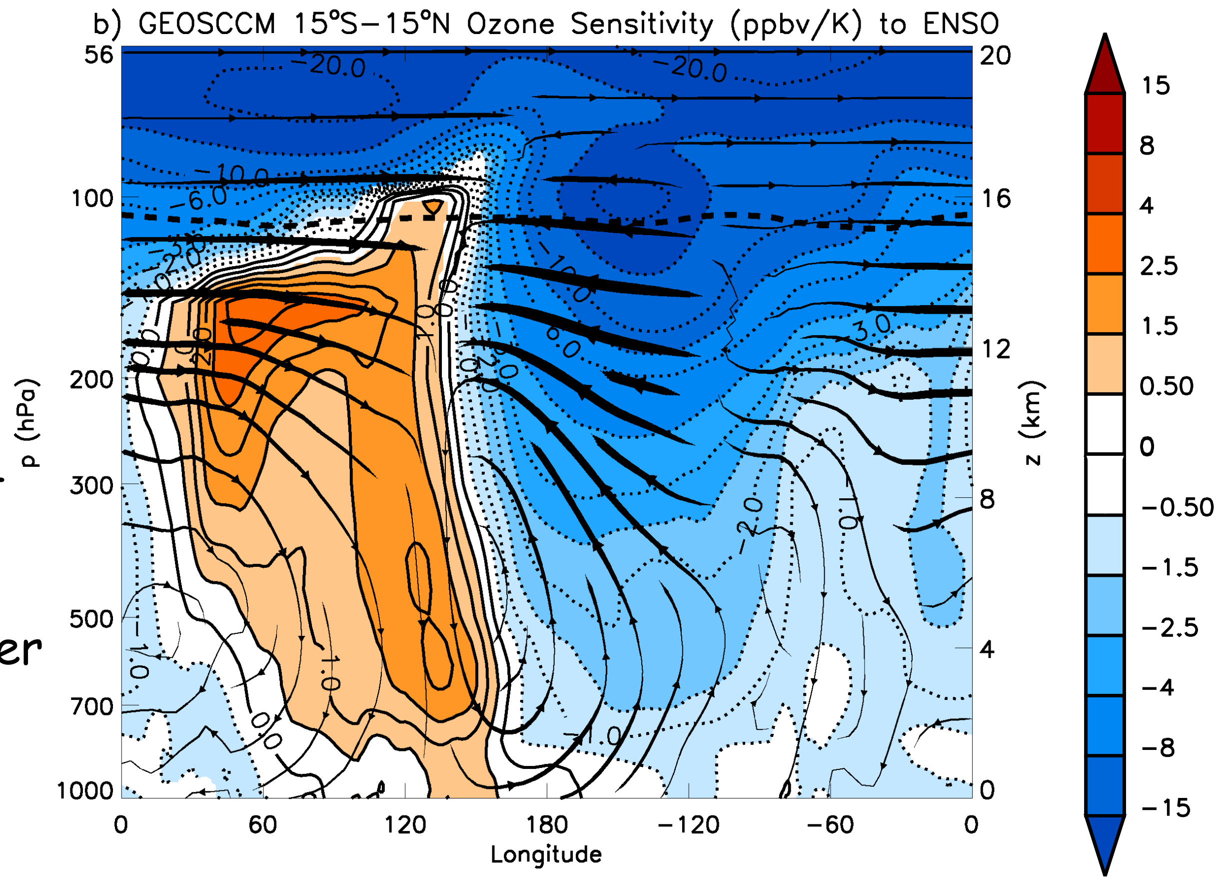
How does ozone and circulation respond to ENSO related variability?

Color contours show the CCMs ozone sensitivity to ENSO (ppbv/K)

The ozone field was deseasonalized and linearly regressed against Niño 3.4 Index

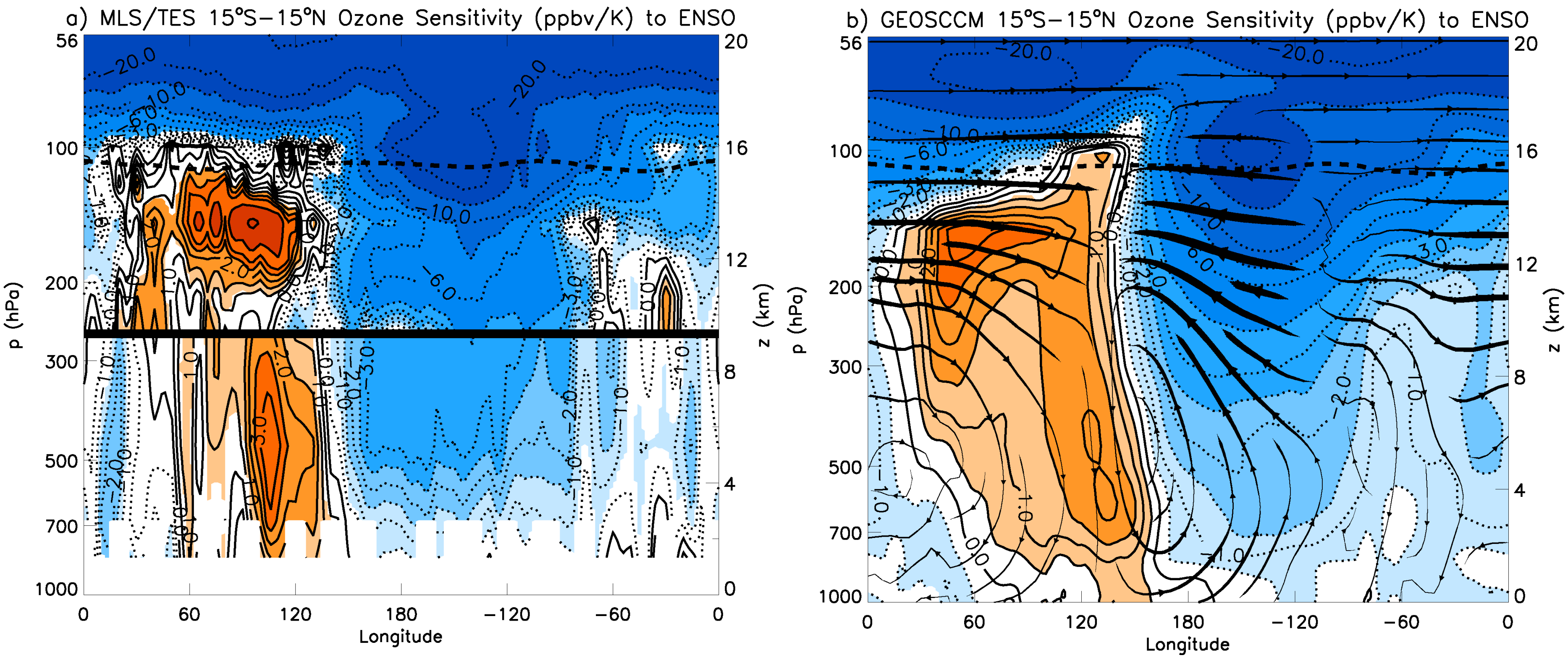
Overlaid is the streamlines resulting from regressing zonal and vertical wind components against Niño 3.4 Index

Positive ozone sensitivity over Indonesia and Indian Ocean region.
Negative ozone sensitivity over central and eastern Pacific that is largest in the upper troposphere.

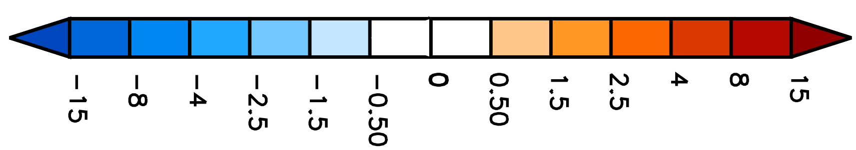


MLS/TES and GEOSCCM ozone sensitivity averaged over the tropics

Negative ozone sensitivities are seen over the eastern and central tropical Pacific and throughout the lower stratosphere.
Positive ozone sensitivities over Indonesia and the Indian Ocean.



Colored contours significant at 1 SD

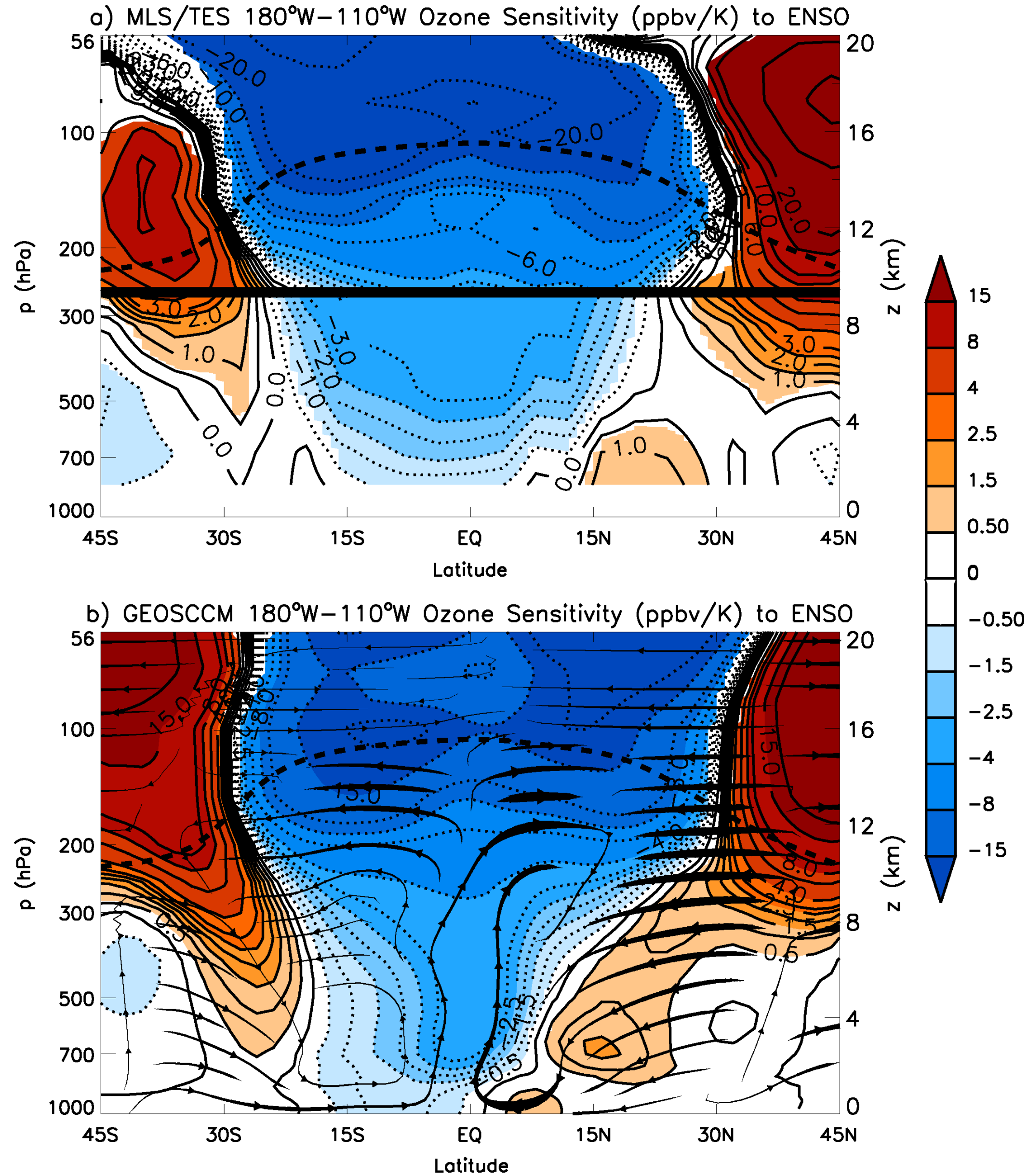


MLS/TES and GEOSCCM ozone sensitivity to ENSO averaged over Eastern and Central Pacific Region

Ozone decreases near the equator with larger values in the UT/LS.

In the midlatitudes increases in ozone occur in the UT/LS which continue into the troposphere in the subtropics.

GEOSCCM shows the same general response although differences can be seen in the LS extratropics

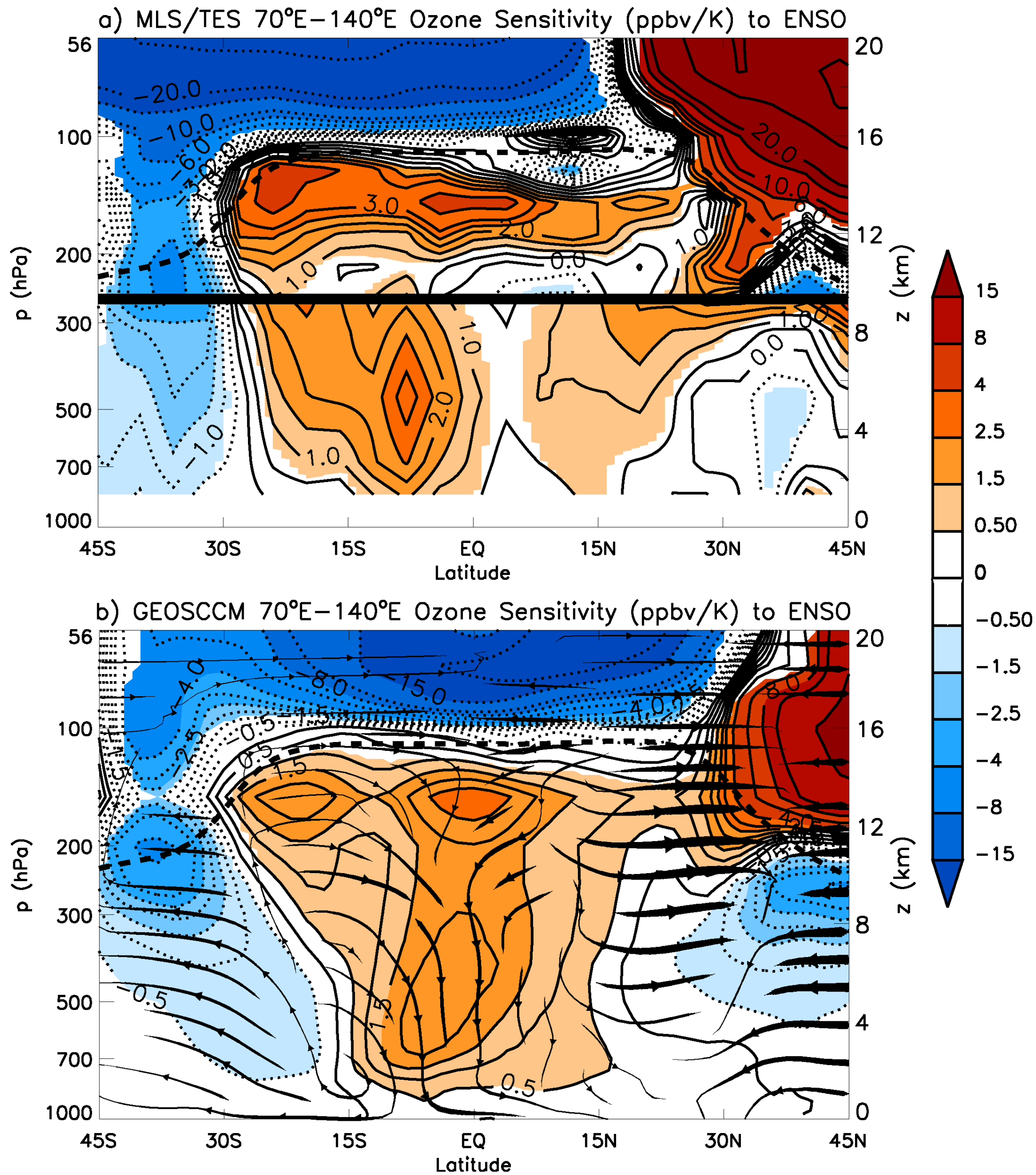


MLS/TES and GEOSCCM ozone sensitivity to ENSO averaged over Indonesia and Indian Ocean Region

Ozone generally increases near the equator in troposphere but decreases in the LS.

In the midlatitudes differences in ozone response occur in the LS of the respective hemispheres.

GEOSCCM shows the same general response as the observation.

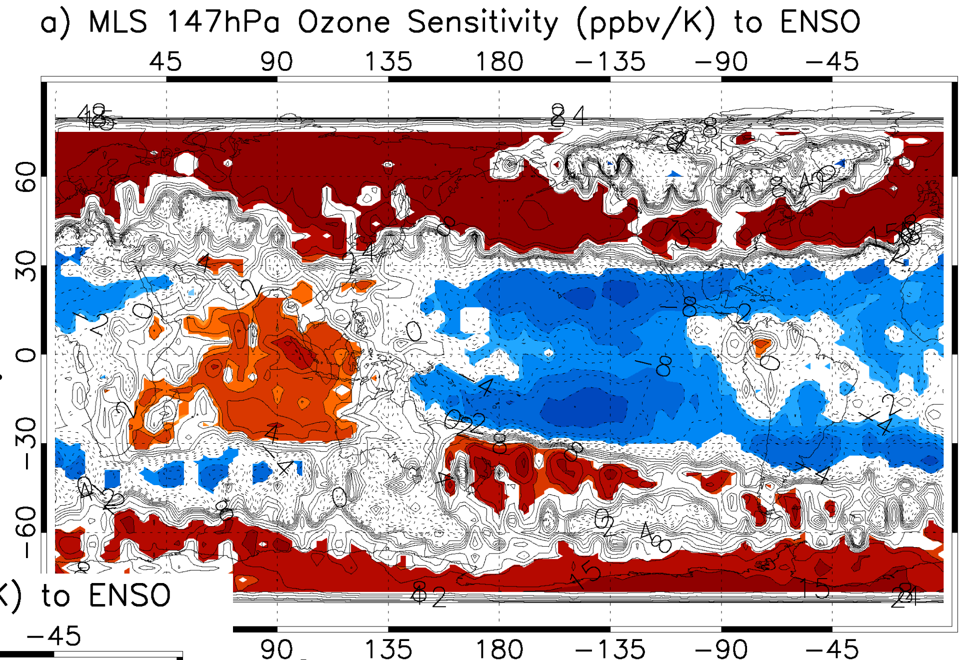


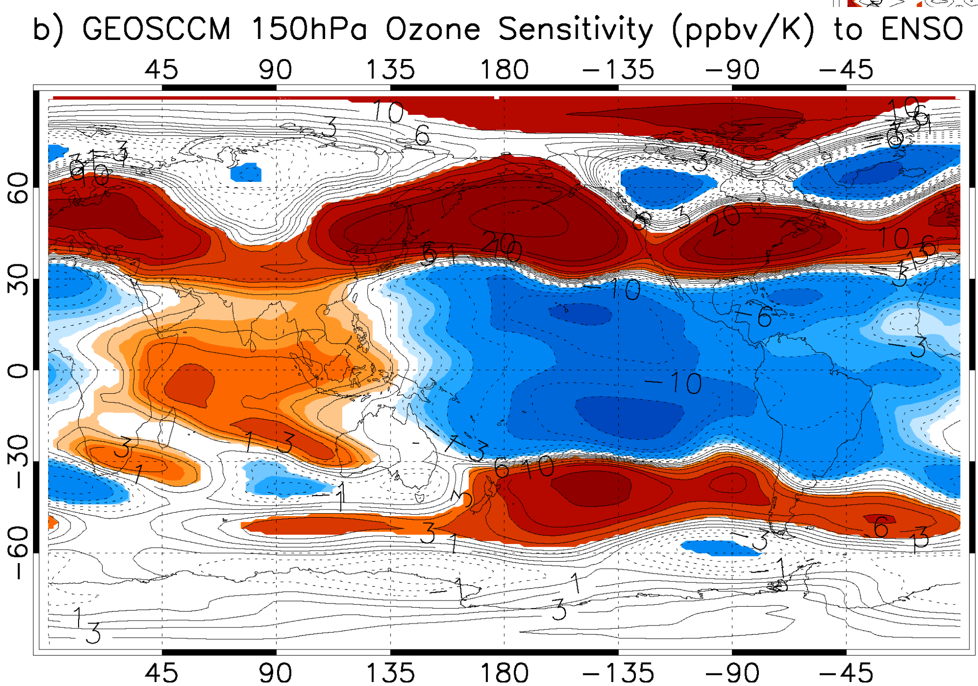
Horizontal Ozone Sensitivity to ENSO at around 150 hPa

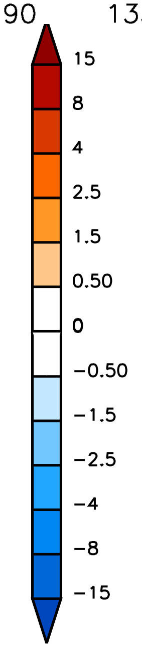
Negative ozone sensitivity over much of the tropical Pacific.

Positive ozone sensitivity over Indonesia and tropical Indian Ocean.

Positive local ozone maxima over midlatitude Pacific.







Some differences over tropical South America and at high latitudes.

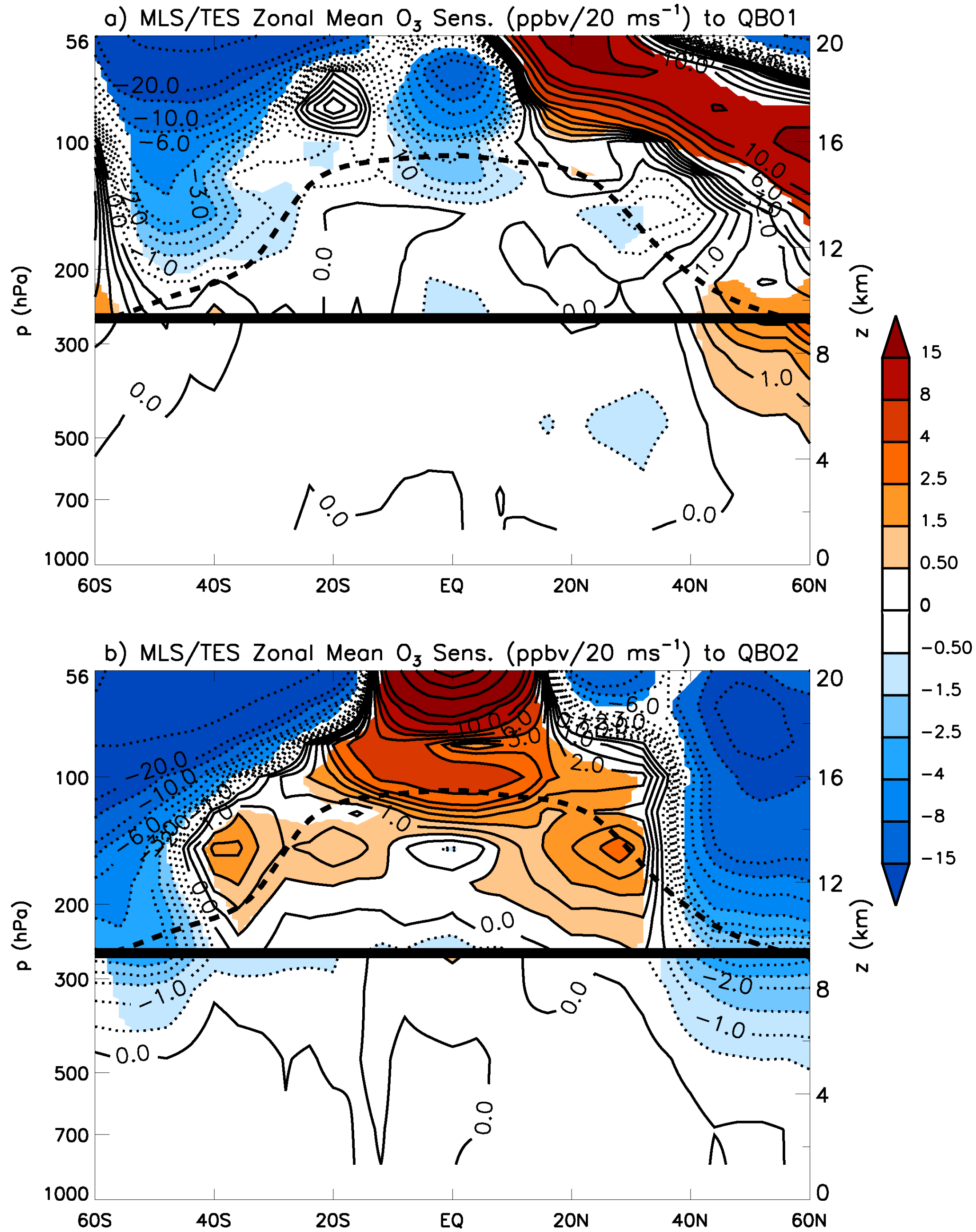
MLS/TES QBO Sensitivities

This preliminary work shows the ozone response to the first 2 EOFs of the QBO.

EOF1 is highly corr. 15 – 70 hPa winds.

QBO EOF2 is highly correlated with winds at 40 hPa so during westerly phase increased ozone in the tropical UT/LS with decreased ozone over midlatitude regions.

We have not yet explored the model response to the QBO but plan to soon.



Conclusions

• ENSO variations are an important driver of tropical tropospheric ozone variability.

• This ozone variability can be derived from MLS and TES measurements and appear to have very good continuity at 261 hPa.

• GEOSCCM can well represent this variability forced with observed SSTs.

• The ozone sensitivities derived from MLS and TES measurements are potentially useful for process evaluation in future CCM assessments.

Reference

Oman, L. D., J. R. Ziemke, A. R. Douglass, D. W. Waugh, C. Lang, J. M. Rodriguez, J. E. Nielsen, 2011: The Response of Tropical Tropospheric Ozone to ENSO, *Geophys. Res. Lett. 38*, L13706, doi:10.1029/2011GL047865.

Oman, L. D., A. R. Douglass, J. R. Ziemke, J. M. Rodriguez, D. W. Waugh, and J. E. Nielsen, 2012: The ozone response to ENSO in Aura satellite measurements and a chemistry climate model, submitted to J. Geophys Res.

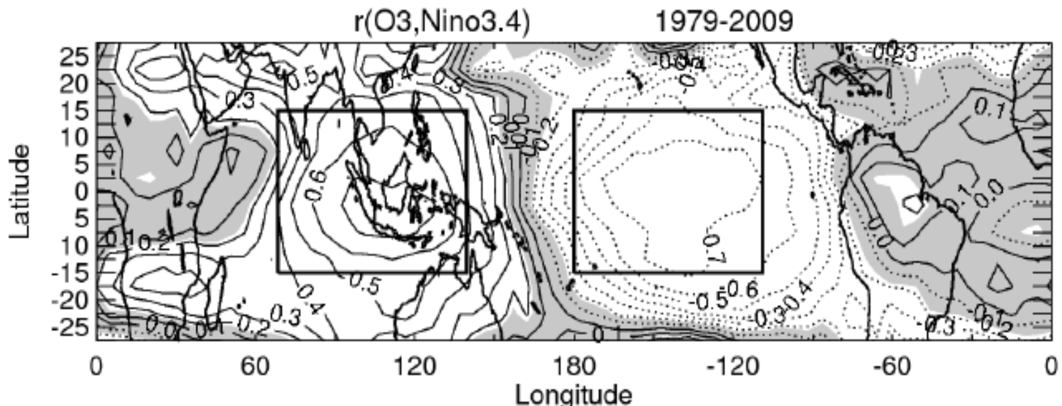
ENSO Related Variability in Ozone

The El Niño Southern Oscillation is the dominant mode of tropical variability on interannual timescales (Philander, 1989).

ENSO is known to cause significant thermal and dynamical perturbations to the atmosphere and also influences the constituent distributions.

Ziemke et al. (2010) showed that ENSO related response of tropical ozone dominated interannual variability and created the Ozone ENSO Index.

OEI = W TCO – E TCO



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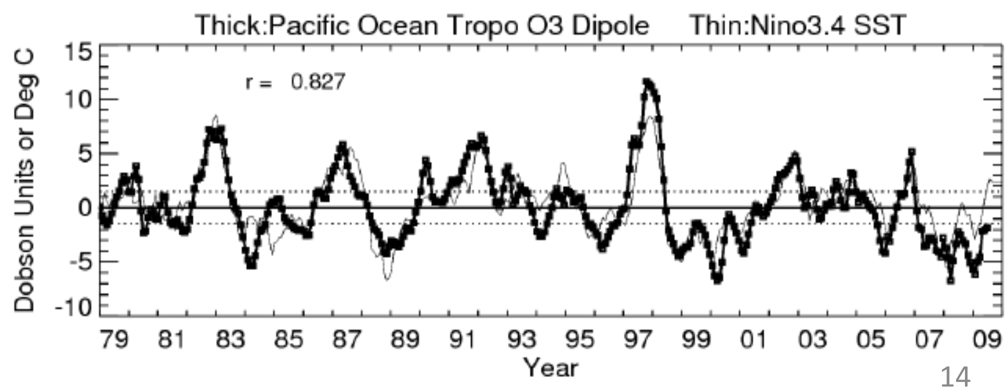
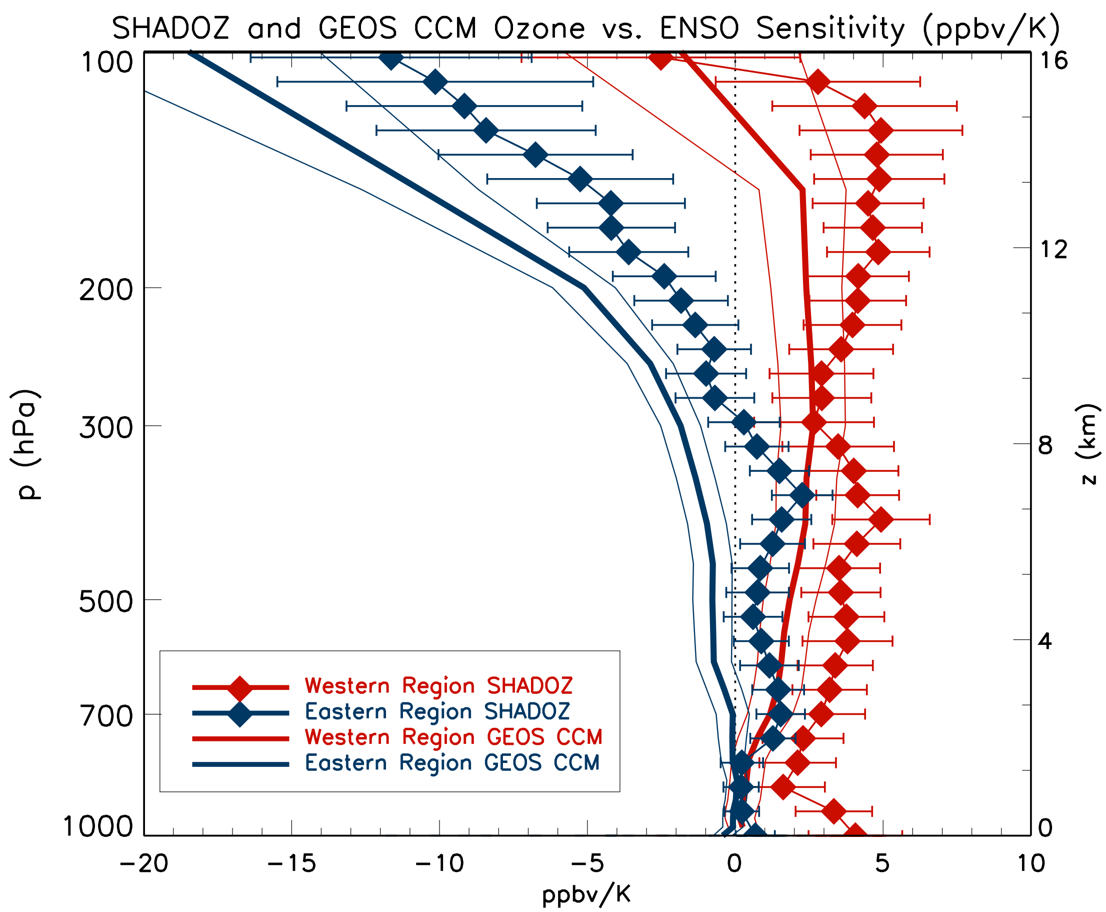


SHADOZ data (Thompson et al., 2003) from 1998-2009 stations were individually deseasonalized, then averaged together and regressed against Niño 3.4 Index



http://tropo.gsfc.nasa.gov/shadoz/

For Western Region used Kuala Lumpur and Watukosek, Java
CCM ~ 2 ppbv/K

For Eastern Region used American Samoa, Hilo, and San Cristobal
CCM ~ -10 to -15 ppbv/K near Tropopause